Appendix D: Model Fitting and Assessing Model Fit

Choosing and validating a model

To describe the influence of chip composition on pulping and handsheet properties, models of increasing complexity were fitted to the data. The three models that were included are a linear, a quadratic and a special cubic model, using the Scheffé mixture polynomials. Mixture experiments are characterized by the constraint that the fractions of all components add up to unity:

Spruce (S) + Lodgepole Pine (P) + Subalpine Fir (F) =1

With this restriction the general cubic equations can be re-parameterized and certain terms can be eliminated. The resulting equations (with *a,b,c,d,e,f,g* the model coefficients) are:

Linear model: $Y = a \cdot S + b \cdot P + c \cdot F$

Quadratic model: $Y = a \cdot S + b \cdot P + c \cdot F + d \cdot S \cdot P + e \cdot S \cdot F + f \cdot P \cdot F$

Special cubic model: $Y = a \cdot S + b \cdot P + c \cdot F + d \cdot S \cdot P + e \cdot S \cdot F + f \cdot P \cdot F + g \cdot S \cdot P \cdot F$

To decide which of the increasingly complex models provides a sufficient fit, the models are compared in a stepwise fashion with the help of ANOVA. The STATISTICA software was used to produce the ANOVA analysis and also for subsequent model evaluation. Consider the following example of fitting the model equations to the observed data for tear after thermomechanical pulping of site 1 trees. The ANOVA analysis returns the following result (**Table D-27**):

Table D-27. Example tear (TMP site 1): ANOVA-table

	ANOVA; Var.:Tear Index(mN·m2/g) (MPB SPF Site 1 TMP) 3 Factor mixture design; Mixture total=100., 14 Runs Sequential fit of models of increasing complexity									
Model	SS Effect	df Effect	MS Effect	SS Error	df Error	MS Error	F	p	R-Sqr	R-Sqr Adjusted
Linear	0.397103	2	0.198551	0.711447	11	0.064677	3.069893	0.087223	0.358218	0.241531
Quadratic	0.513070	3	0.171023	0.198376	8	0.024797	6.896932	0.013107	0.821049	0.709204
Special Cubic	0.007415	1	0.007415	0.190961	7	0.027280	0.271828	0.618192	0.827738	0.680085
Total Adjusted	1.108549	13	0.085273							

Choosing an alpha (α) level of significance of 0.05 for all statistical tests, we can use the p-values to evaluate model significance. In the above example, the linear equations with a p-value >0.05 do not provide a statistically significant model. Adding second order parameters does significantly improve the model fit ($p<0.05$ for quadratic model, compared to linear model), but adding third order terms does not further improve the model significantly ($p>0.05$). Thus, we consider a quadratic model. Also from the ANOVA table we can read the R^2 value as an estimate of the goodness of fit. Next we look at a list of the calculated model factors and their significance, to check whether the model could be simplified by excluding terms that are not significant (Table D-28).

Table D-28. Example tear (TMP site 1): Estimated model coefficients for a quadratic model

	Coeffs (recoded comps); Var.:Tear Index(mN·m2/g); R-sqr=.821; Adj:.7092 (MPB SPF Site 1 TMP) 3 Factor mixture design; Mixture total=100., 14 Runs DV: Tear Index(mN·m2/g); MS Residual=.024797					
Factor	Coeff.	Std.Err.	t(8)	p	-95.% Cnf.Limt	+95.% Cnf.Limt
(A)S (%)	8.602339	0.109144	78.81670	0.000000	8.350654	8.854025
(B)P (%)	8.474862	0.109144	77.64872	0.000000	8.223176	8.726547
(C)F (%)	9.068764	0.109144	83.09019	0.000000	8.817078	9.320450
AB	1.747177	0.614836	2.84169	0.021755	0.329362	3.164992
AC	0.470608	0.614836	0.76542	0.466001	-0.947208	1.888423
BC	1.718597	0.614836	2.79521	0.023370	0.300782	3.136412

Only the linear parameters as well as the interaction parameters between AB (spruce and pine) and BC (pine and fir) are of significance, thus we omit the interaction term AC (spruce and fir) from the model equations and fit this reduced quadratic model to the data. We then check with a new ANOVA analysis if the model is still a significant improvement over lower order models. Also, we need to confirm that the model in itself is significant and there is no lack of fit of the model. A lack of fit is given if the residual variability (sum of squares of residuals) significantly exceeds the pure error variability (sum of squares of pure error) that is calculated from the replicate runs. Lack of fit of the model indicates that there are other major effects on mixture behaviour that are not accounted for in the model. Lack of fit and model significance can be checked in the table assessing overall model fit (**Table D-29**).

Table D-29. Example tear (TMP site 1): Overall fit of quadratic model (factor AC excluded)

	Overall Fit of Model; Var.: Tear Index(mN·m 2/g) (MPB SPF Site 1 TM 3 Factor mixture design; Mixture total=100., 14 Runs (Some terms were excluded from the respective full models)				
Source	SS	df	MS	F	p
Model	0.895645	4	0.223911	9.465307	0.002764
Total Error	0.212904	9	0.023656		
Lack of Fit	0.058647	5	0.011729	0.304151	0.888039
Pure Error	0.154257	4	0.038564		
Total Adjusted	1.108549	13	0.085273		

For our example, the reduced quadratic model is significant ($p_{model}<0.05$), and there is no significant lack of fit ($p_{lack\_of\_fit}>0.05$). We thus decide to use this reduced quadratic model, pending further validation of the model.

In multiple regression, it is assumed that the residuals are distributed normally around zero with constant variance. Thus, residuals should be carefully examined for outliers and the validity of these assumptions. Also, the general data should be reviewed for obvious outliers. The following plots were thus reviewed:

- The scatterplot of predicted versus residual value. This should show a random distribution, as the model should capture all significant effects.
- The normal probability plot of the residuals. Given the assumption of normal residual distribution, all residuals should fall on or close to the line. Any apparent trend in

deviation from the straight line needs to be further considered. Sometimes, it is possible to alleviate such a problem by considering data transformation; however this did not prove successful for cases with non-normal residual distribution in this study. The histogram of residual distribution can also be used to validate the normality assumption.

- The scatterplot of observed versus predicted values, together with a table of observed, predicted and residual values, to identify possible outliers. The normal probability plot also helps revealing possible outliers.

The plots for the example from before are shown below (**Figure D-39** to **Figure D-42**). Obviously, the residuals are reasonably normally distributed, are randomly distributed compared to predicted values, and there are no apparent outliers in the data.

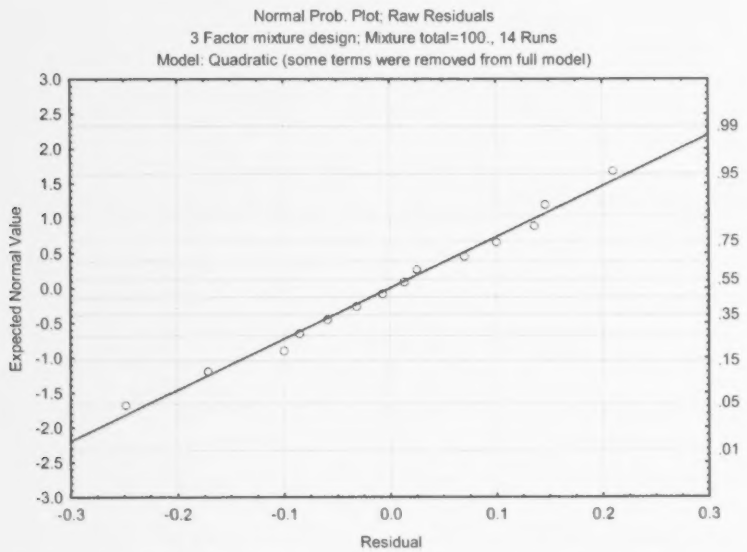

Figure D-39. Example tear (TMP site 1): Normal probability plot of residuals

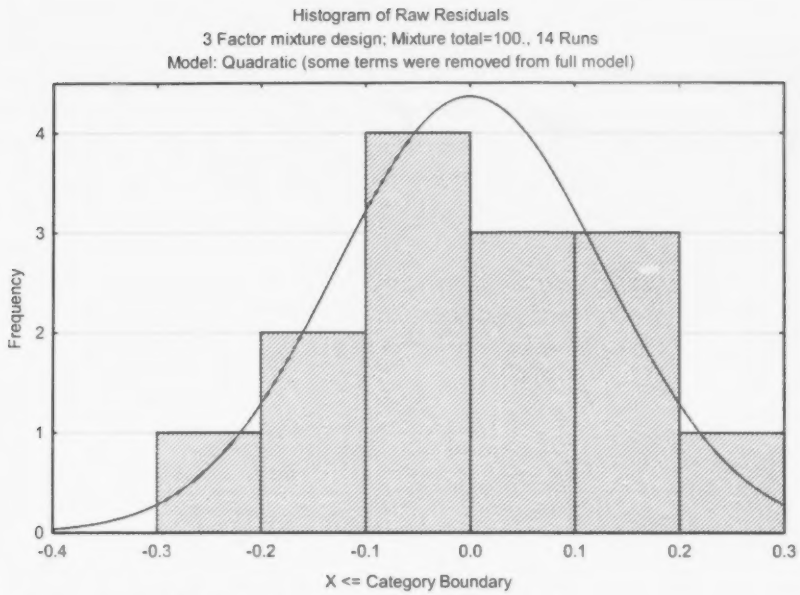

Figure D-40. Example tear (TMP site 1): Histogram of residuals

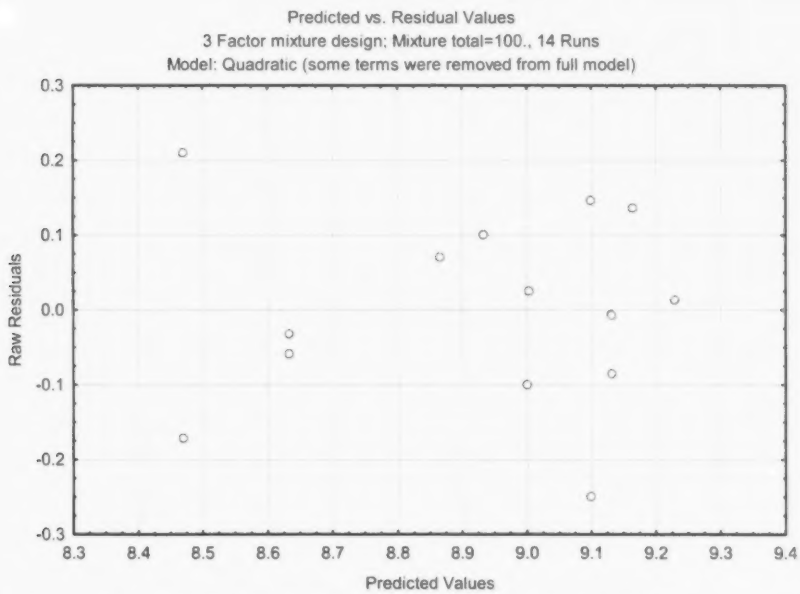

Figure D-41. Example tear (TMP site 1): Predicted versus residual values

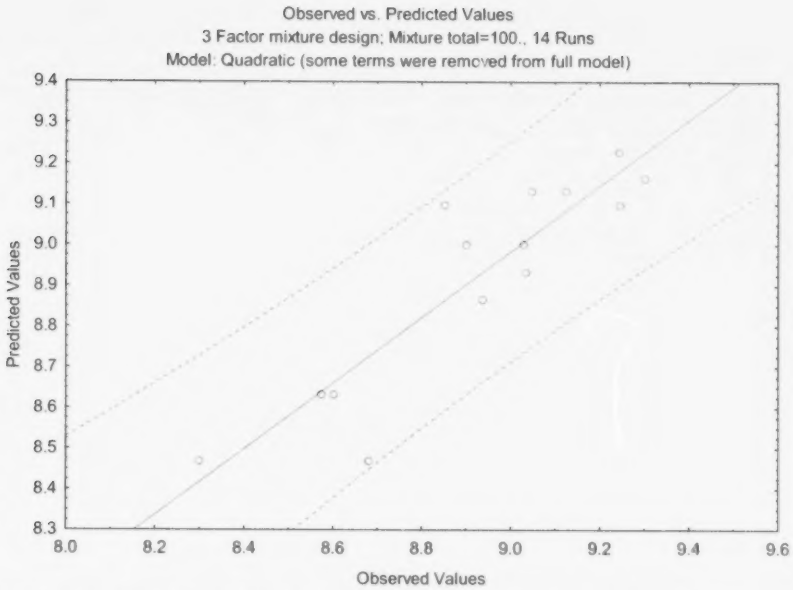

Figure D-42. Example tear (TMP site 1): Observed versus predicted values

Procedure for possible outliers

In general, no data points were found that were obviously outliers. However, some data points were in a range where they could be outliers, but did not necessarily have to be. The following was done to decide if they are outliers and should be omitted, or if they are valid data points.

First, the model fitting was repeated without these outliers. In some cases, this did not improve the data fit and in these cases the data points were kept in the data set. If omitting the data point improved the model fit significantly (while at the same time not influencing the calculated model parameters too much), the data point was reviewed in light of the overall data set before deciding to finally exclude it from the data set. For example, if the data point in question was a single species point which showed a much higher value for a certain property than the rest of the data set, but the species in question is known to produce high values for this property, one cannot justify to exclude the data point. However, if it is a mixture of two species that returns a very high value, while both the single species return a much lower value for the given property, then the data point is likely bad data that should be omitted. (This arguing holds only if not much interaction is seen between the different species. However, this was the case for most properties that were investigated. There are only very few properties that show considerable interactions between two species.)

Further validation using the validation points

Two experimental runs were done with mixtures where the results were not included in the data set for fitting a model. These data points were used to verify that the chosen model adequately predicts mixture properties. To check this, predicted values for all properties using the model equations were compared to the measured ones. It was confirmed that the measured points fall within the 95% confidence interval of the predicted values, using the scatterplot of predicted versus observed as shown above (**Figure D-42**). Also, it was checked that the residuals of the predicted validation points lie within the same range as the model residuals. If the validation point were not predicted according to these criteria, the model was considered unsatisfactory, and

attempts were made to improve the model (by including higher order terms). If this was not possible, it was concluded that no suitable model could be found based on the given information.

If the model is considered satisfactory, the model results can be visualized by using a contour (2-d) or surface (3-d) plot. The 3-d surface plot is shown below (**Figure 1**).

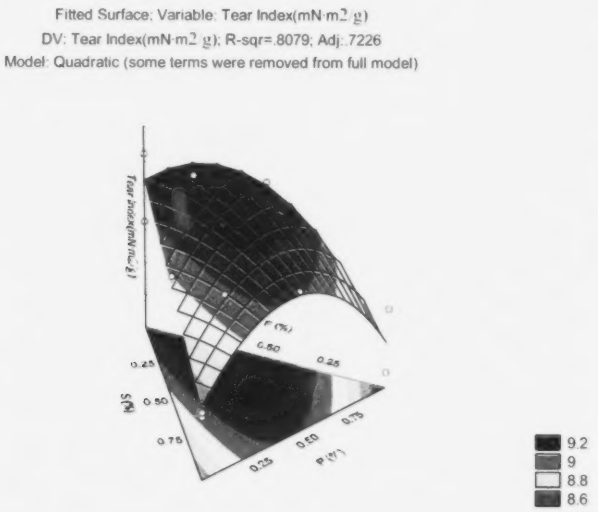

Figure D-43. Example tear (TMP site 1): Surface plot of predicted response surface, and comparison with observed values

A note about choosing the model: As described earlier, the ANOVA table was used to choose the model equations. In some cases, a lower order model predicted the response sufficiently, but higher order models would significantly improve the model. Even though, in general the lower order model was used pending further validation. The higher order model was only considered if the validation showed possible problems with the model. However, in a few cases where the model improvement was very significant (e.g., doubling of R^2 value or similar), or where the specific response was believed to include interaction terms (as would be the case for tear strength, according to experience from other literature), the higher order model was chosen over a linear model, even if the linear model was sufficient.

Appendix E: Fibre length and width distribution profiles (kraft pulp)

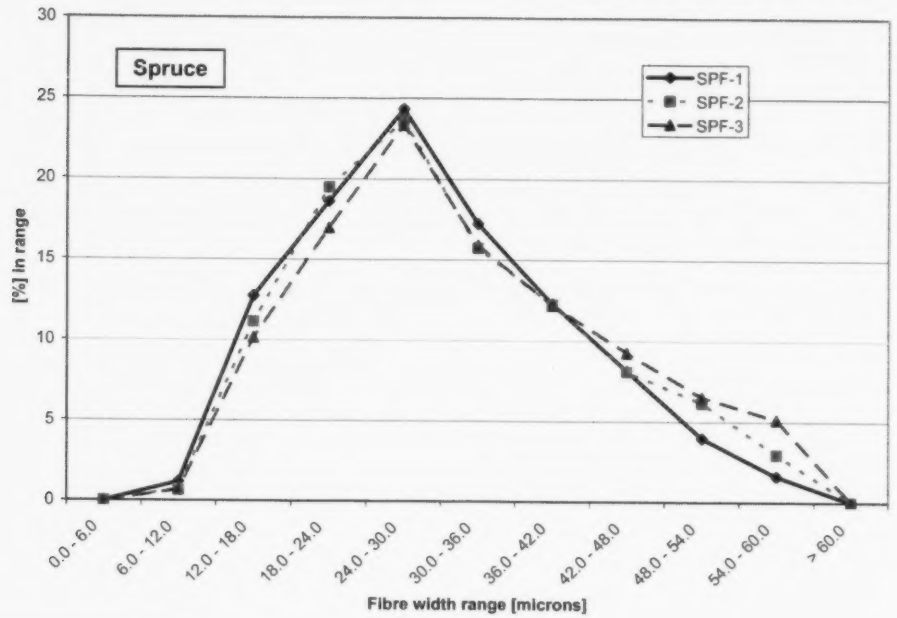

Figure E-44. Fibre width distribution of spruce kraft pulp fibres

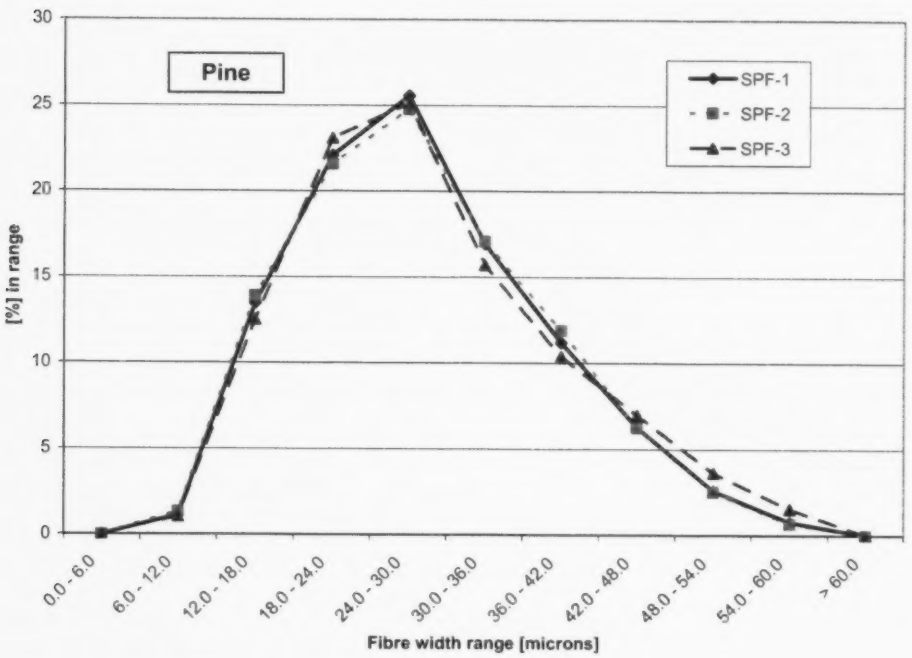

Figure E-45. Fibre width distribution of pine kraft pulp fibres

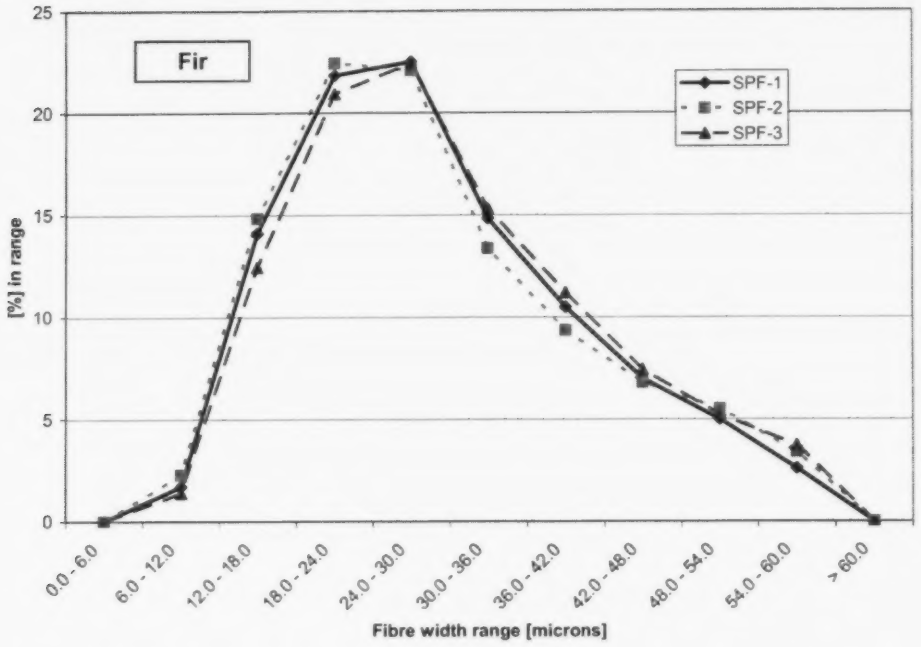

Figure E-46. Fibre width distribution of fir kraft pulp fibres

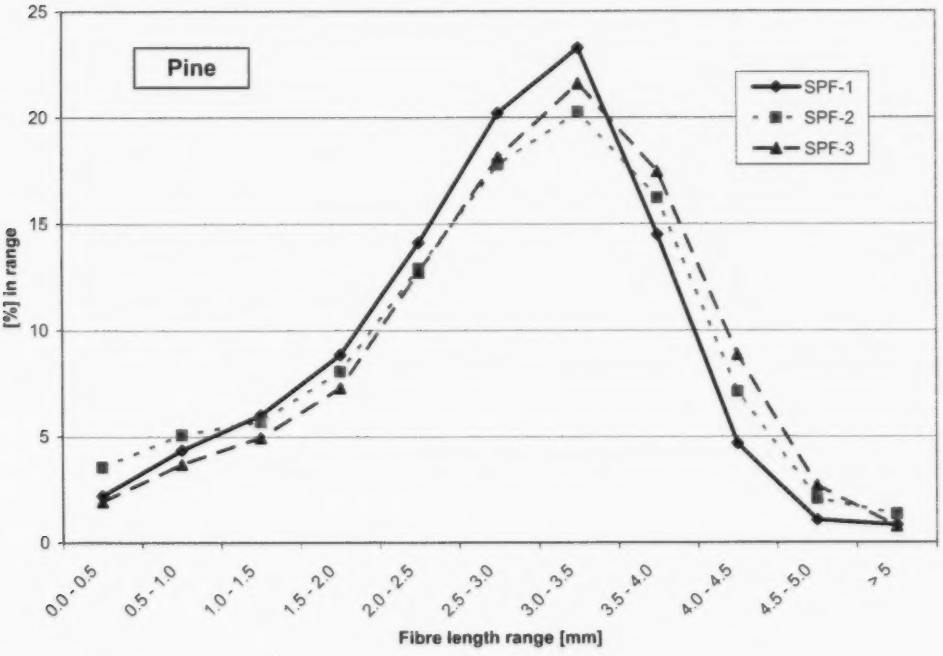

Figure E-47. Fibre length distribution of pine kraft pulp fibres

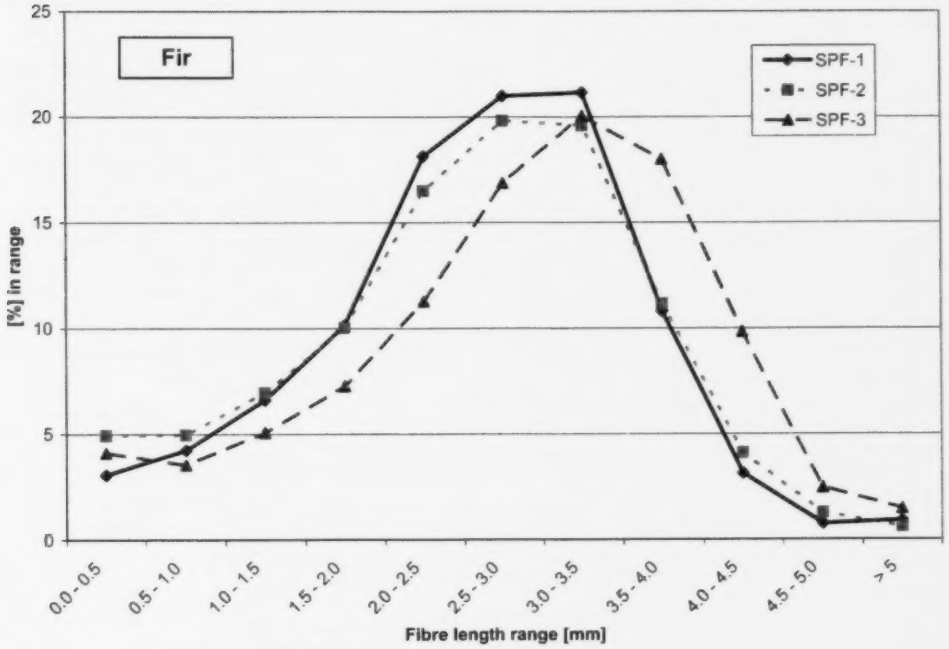

Figure E-48. Fibre length distribution of fir kraft pulp fibres

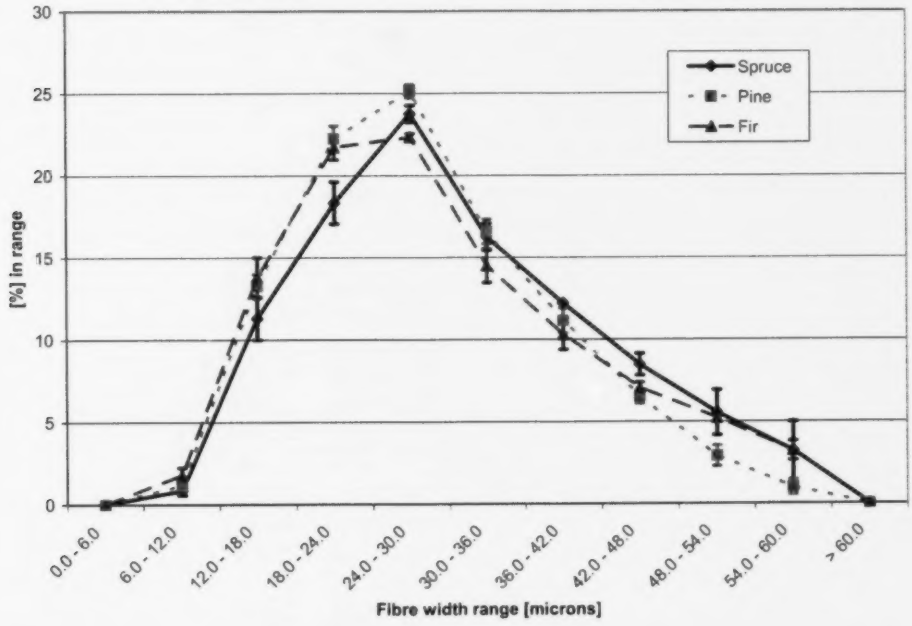

Figure E-49. Fibre width distribution of spruce, pine and fir kraft pulp averaged over three sample sites. Error bars denote the standard deviation.

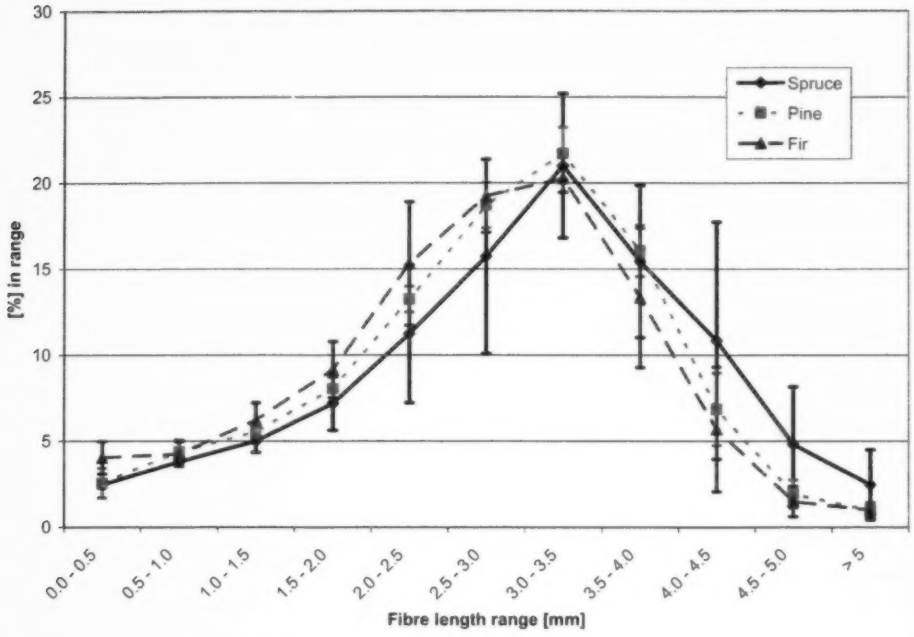

Figure E-50. Fibre length distribution of spruce, pine and fir kraft pulp averaged over three sample sites. Error bars denote the standard deviation.

Appendix F: Model Equations

Table F-30. Model equations for kraft pulp after PFI refining (CSF = 300 ml)

Pulp Property	Site	Model equation
Kappa Number	SPF-1	31.8**S* + 31.1**P* + 36.9**F*
	SPF-2	31.1**S* + 30.2**P* + 35.7**F*
	SPF-3	30.2**S* + 31.1**P* + 35.2**F*
Pulp yield [%]	SPF-1	47.1**S* + 43.8**P* + 46.5**F*
	SPF-2	48.1**S* + 45.7**P* + 46.1**F*
	SPF-3	48.3**S* + 44.3**P* + 47.4**F*
Length weighted fibre length [mm]	SPF-1	2.66**S* + 2.72**P* + 2.60**F*
	SPF-2	3.08**S* + 2.82**P* + 2.60**F*
	SPF-3	3.19**S* + 2.92**P* + 2.94**F*
Coarseness [mg/m]	SPF-1	0.153**S* + 0.147**P* + 0.146**F*
	SPF-2	0.172**S* + 0.150**P* + 0.136**F*
	SPF-3	0.187**S* + 0.166**P* + 0.168**F*
Sheet density [kg/m^3]	SPF-1	N/A
	SPF-2	691**S* + 704**P* + 717**F*
	SPF-3	692**S* + 688**P* + 681**F*
Burst index [kPa·m^2/g]	SPF-1	11.4**S* + 11.8**P* + 12.8**F* + 3.08**S***P*
	SPF-2	N/A
	SPF-3	11.4**S* + 10.8**P* + 11.2**F* + 2.78**P***F* + 1.81**S***F*
Tensile index [N·m/g]	SPF-1	125.7**S* + 123.1**P* + 133.6**F*
	SPF-2	N/A
	SPF-3	N/A
Tear index 1-ply [mN·m^2/g]	SPF-1	N/A
	SPF-2	12.1**S* + 11.8**P* + 13.7**F*
	SPF-3	N/A
Tear index 4-ply [mN·m^2/g]	SPF-1	N/A
	SPF-2	11.6**S* + 11.7**P* + 13.5**F*
	SPF-3	N/A
Gurley air resistance [s/100ml]	SPF-1	58.0**S* + 57.3**P* + 123.2**F*
	SPF-2	146.3**S* + 128.7**P* + 131.5**F* -1144**S***P***F*
	SPF-3	137.9**S* + 71.3**P* + 175.1**F*
Sheffield roughness [SU]	SPF-1	99.7**S* + 98.1**P* + 71.7**F*
	SPF-2	77.5**S* + 71.8**P* + 69.6**F* - 39.0**P***F*
	SPF-3	67.0**S* + 87.6**P* + 78.5**F*
ISO Opacity [%]	SPF-1	88.8**S* + 90.3**P* + 91.3**F*
	SPF-2	87.7**S* + 89.9**P* + 90.7**F*
	SPF-3	87.3**S* + 90.1**P* + 92.6**F*
Scattering coefficient [cm^2/g]	SPF-1	N/A
	SPF-2	138.6**S* + 141.8**P* + 150.1**F*
	SPF-3	129.6**S* + 148.7**P* + 147.0**F*
Zero span breaking length [km]	SPF-1	16.9**S* + 17.3**P* + 18.1**F* + 9.10**P***F*
	SPF-2	18.3**S* + 19.7**P* + 18.4**F* + 6.17**S***F* - 42.7* *S***P***F*
	SPF-3	17.7**S* + 19.2**P* + 18.8**F*

Note: *S,P,F* are fractions of Spruce, Pine and Fir in the mixture
Highlighted model equations are for models where the p-level of significance was low (0.1>p>0.05) and thus should not be used to predict pulp or handsheet properties

Table F-31. Model equations for TMP pulp (CSF = 100 ml)

Pulp Property	Site	Model equation
SRE [MJ/kg]	SPF-1	11.6*S + 11.8*P + 11.1*F - 2.07*S*P
	SPF-2	N/A
	SPF-3	11.1*S + 11.5*P + 9.4*F + 4.83*S*F
Length weighted fibre length [mm]	SPF-1	1.96*S + 1.84*P + 1.94*F - 0.520*P*F
	SPF-2	1.98*S + 1.85*P + 1.75*F
	SPF-3	1.98*S + 1.87*P + 2.01*F + 0.476*S*P
Fines fraction (P-200) [%]	SPF-1	25.7*S + 27.8*P + 25.9*F - 9.07*P*F - 47.0*S*P*F
	SPF-2	24.3*S + 26.7*P + 26.4*F
	SPF-3	27.1*S + 27.2*P + 23.1*F
Long fibre fraction (R-48) [%]	SPF-1	61.6*S + 58.8*P + 60.6*F
	SPF-2	62.8*S + 60.6*P + 59.6*F
	SPF-3	60.9*S + 60.1*P + 62.4*F
Sheet density [kg/m^3]	SPF-1	377*S + 344*P + 346*F
	SPF-2	360*S + 355*P + 341*F
	SPF-3	374*S + 343*P + 328*F
Burst index [kPa·m^2/g]	SPF-1	3.37*S + 2.83*P + 3.04*F
	SPF-2	3.11*S + 2.97*P + 2.77*F + 0.608*S*F + 0.667*P*F
	SPF-3	3.39*S + 2.77*P + 2.89*F
Tensile index [N·m/g]	SPF-1	49.0*S + 42.7*P + 42.5*F
	SPF-2	46.1*S + 41.4*P + 42.9*F
	SPF-3	45.7*S + 40.5*P + 40.8*F
Tear index [mN·m^2/g]	SPF-1	8.63*S + 8.47*P + 9.10*F + 1.81*S*P + 1.78*P*F
	SPF-2	8.80*S + 8.54*P + 8.90*F + 1.42*S*P + 1.12*P*F - 1.39*S*F - 13.77*S*P*F
	SPF-3	9.11*S + 8.66*P + 9.30*F
Sheffield roughness [SU]	SPF-1	178*S + 225*P + 192*F
	SPF-2	231*S + 226*P + 225*F - 130*S*F
	SPF-3	190*S + 248*P + 240*F
Brightness [%]	SPF-1	N/A
	SPF-2	N/A
	SPF-3	57.5*S + 53.6*P + 53.5*F
ISO Opacity [%]	SPF-1	95.6*S + 96.9*P + 96.4*F
	SPF-2	96.2*S + 96.9*P + 97.6*F
	SPF-3	95.5*S + 97.7*P + 97.2*F
Scattering coefficient [cm^2/g]	SPF-1	574*S + 609*P + 608*F
	SPF-2	557*S + 616*P + 631*F
	SPF-3	582*S + 620*P + 594*F

Note: *S,P,F* are fractions of Spruce, Pine and Fir in the mixture
Highlighted model equations are for models where the p-level of significance was low (0.1>p>0.05) and thus should not be used to predict pulp or handsheet properties

Table F-32. Model equations for TMP pulp (SRE = 10 MJ/kg)

Pulp Property	Site	Model equation
CSF [ml]	SPF-1	136**S* + 160**P* + 130**F* - 92**S***P* - 69**P***F* + 52**S***F*
	SPF-2	N/A
	SPF-3	125**S* + 130**P* + 88**F* - 107**S***F*
Length weighted fibre length [mm]	SPF-1	1.98**S* + 1.86**P* + 1.99**F* - 0.520**P***F*
	SPF-2	1.98**S* + 1.89**P* + 1.76**F*
	SPF-3	1.98**S* + 1.90**P* + 2.01**F* + 0.441**S***P*
Sheet density [kg/m^3]	SPF-1	350**S* + 318**P* + 324**F*
	SPF-2	346**S* + 335**P* + 333**F*
	SPF-3	351**S* + 322**P* + 337**F* - 172.6**S***F*
Tensile index [N·m/g]	SPF-1	43.8**S* + 36.5**P* + 39.0**F*
	SPF-2	43.7**S* + 39.0**P* + 41.0**F*
	SPF-3	41.2**S* + 35.8**P* + 41.4**F*
Tear index [mN·m^2/g]	SPF-1	N/A
	SPF-2	9.07**S* + 9.20**P* + 8.74**F*
	SPF-3	9.94**S* + 9.43**P* + 9.02**F* + 2.19**S***F*
Sheffield roughness [SU]	SPF-1	202**S* + 264**P* + 221**F*
	SPF-2	234**S* + 257**P* + 235**F* - 106**P***F*
	SPF-3	219**S* + 268**P* + 239**F*
Scattering coefficient [cm^2/g]	SPF-1	556**S* + 597**P* + 584**F*
	SPF-2	548**S* + 591**P* + 622**F*
	SPF-3	566**S* + 606**P* + 596**F*

Note: *S,P,F* are fractions of Spruce, Pine and Fir in the mixture
Highlighted model equations are for models where the p-level of significance was low (0.1>p>0.05) and thus should not be used to predict pulp or handsheet properties

Appendix G: Escher-Wyss refining results

Table G-33. CSF and handsheet data after Escher-Wyss refining of pure species pulps

Species	SEL (J/m)	Spec. Refining Energy (MJ/kg)	CSF (ml)	App. Sheet Density (kg/m3)	Burst Index (kPa·m2/g)	Tensile Index (N·m/g)	Tear Index (1 ply) (mN·m2/g)	Zero Span Breaking Length (km)	Gurley Air Resistance (sec/100ml)	Sheffield Roughness (SU)	ISO Opacity (%)	Scattering Coefficient (cm2/g)
Spruce	1.0	0	710	569	7.3	86.7	16.2	17.1	4.7	242	94.5	227
		99.7	614	635	9.8	110.2	13.5	15.8	20.8	170	92.5	180
		149.2	560	638	10.4	121.9	12.8	16.7	29.5	145	91.2	174
		199	446	658	10.8	122.6	12.7	16.4	67.8	92	90.5	160
		249.7	359	669	10.6	112.1	11.6	16.6	205.8	67	90.0	158
Spruce	2.5	0	710	569	7.3	86.7	16.2	17.1	4.7	242	94.5	227
		49.2	666	601	9.2	110.5	14.0	19.9	9.3	214	93.5	205
		151.3	495	650	9.8	121.1	13.1	19.7	38.7	120	91.2	172
		202.7	353	691	9.8	123.7	11.9	18.3	279.8	52	89.9	154
		255	202	686	9.5	112.6	10.4	18.2	> 1800	51	89.9	150
Pine	1.0	0	703	567	7.3	90.6	13.8	18.1	4.4	235	96.2	254
		98.2	590	644	9.7	110.4	12.2	18.4	18.6	166	94.2	197
		147.4	506	653	10.2	126.3	11.1	17.7	41.2	130	92.3	180
		196.8	390	681	10.1	129.7	10.8	17.6	123.8	75	90.8	160
		246.6	258	692	10.7	130.1	10.3	17.0	639.1	41	90.6	157
Pine	2.5	0	703	567	7.3	90.6	13.8	18.1	4.4	235	96.2	254
		50.5	662	608	8.6	112.7	0.0	18.3	7.1	220	94.6	219
		149.8	456	678	9.6	121.2	0.0	18.0	41.6	101	91.3	168
		204.2	309	700	9.2	120.5	0.0	17.7	398.3	39	91.2	165
		253.3	169	731	9.3	117.1	0.0	17.0	> 1800	39	90.0	146
Fir	1.0	0	680	575	7.7	99.0	14.4	18.8	10.6	175	96.6	269
		48.6	636	632	8.9	103.6	13.1	19.7	24.6	145	96.0	222
		149.8	512	670	10.4	121.6	11.4	19.4	63.9	95	94.4	185
		200.8	415	685	9.8	125.5	11.0	20.3	203.5	50	94.0	179
		252.4	324	712	10.2	125.2	10.5	19.7	911.2	40	93.8	165
Fir	2.5	0	680	575	7.7	99.0	14.4	18.8	10.6	175	96.6	269
		47.7	636	622	9.1	103.8	14.4	19.8	22.4	153	96.2	227
		149.4	429	684	9.4	112.0	11.8	18.6	250.8	73	94.8	186
		199.2	280	708	9.4	117.0	10.3	18.6	1295.2	30	93.5	163
		252.1	175	746	9.1	113.7	9.2	17.5	> 1800	28	92.6	145

Table G-34. CSF and handsheet data after Escher-Wyss refining of mixture pulps

Species Mix	SEL (J/m)	Spec. Refining Energy (MJ/kg)	CSF (ml)	App. Sheet Density (kg/m3)	Burst Index (kPa·m2/g)	Tensile Index (N·m/g)	Tear Index (1 ply) (mN·m2/g)	Zero Span Breaking Length (km)	Gurley Air Resistance (sec/100ml)	Sheffield Roughness (SU)	ISO Opacity (%)	Scattering Coefficient (cm2/g)
M65 (30/65/5 S/P/F)	1.0	0	697	556	7.1	90.0	16.2	21.2	3.1	241	96.2	259
		50.6	671	608	9.0	101.9	13.6	17.7	6.0	209	94.0	209
		152.5	491	661	10.1	115.6	11.5	17.0	57.6	122	91.8	174
		202.7	371	686	10.5	120.3	11.0	17.5	144.3	82	90.6	156
		252.7	256	710	10.7	124.3	10.4	17.3	1224.7	35	90.3	152
M65 (30/65/5 S/P/F)	2.5	0	697	556	7.1	90.0	16.2	21.2	3.1	241	96.2	259
		48.7	631	606	8.6	99.7	14.3	19.1	6.2	223	94.6	216
		148.4	380	668	9.5	110.2	11.3	17.0	39.5	131	92.1	171
		198.5	230	696	9.5	112.7	10.7	17.2	203.1	59	91.3	160
		250.1	124	717	9.3	109.8	10.3	16.4	1626.8	33	90.7	149
M90 (10/90/0 S/P/F)	1.0	0	703	548	7.2	93.0	14.4	21.1	2.3	250	96.5	271
		46.3	657	609	8.8	103.3	14.0	17.6	6.3	216	94.3	209
		154.9	461	667	10.1	111.8	12.4	17.0	58.8	111	91.8	163
		196.9	294	694	10.2	121.9	11.8	18.2	327.9	54	91.1	154
		248.1	163	714	10.6	124.1	10.1	17.0	> 1800	39	89.9	143
M90 (10/90/0 S/P/F)	2.5	0	703	548	7.2	93.0	14.4	21.1	2.3	250	96.5	271
		48.2	659	614	8.8	97.3	13.8	18.4	6.7	212	94.4	212
		147.2	423	677	9.7	108.7	11.3	17.0	67.6	91	92.4	170
		198.5	257	706	9.5	117.4	10.0	18.2	1111.4	37	90.5	154
		248.3	142	731	9.1	112.1	9.6	15.7	> 1800	53	89.8	138

Table G-35. BauerMcNett distributions of pulps before and after Escher-Wyss refining (SRE = 250 kWh/t)

Sample	Mesh Size	Unrefined Fraction (%)	SEL = 1J/m Fraction (%)	SEL = 2.5 J/m Fraction (%)
Spruce	R14	71.41	57.79	38.38
	R28	13.24	15.53	22.36
	R48	8.51	13.87	21.04
	R100	2.13	4.39	1.67
	R200	0.49	2.00	8.18
	P200	4.22	6.42	13.15
Pine	R14	68.40	37.31	19.93
	R28	15.23	22.38	30.73
	R48	11.63	17.85	26.36
	R100	2.68	5.26	0.91
	R200	0.78	2.28	10.34
	P200	1.28	14.92	15.22
Fir	R14	62.65	28.55	6.87
	R28	17.86	29.93	32.32
	R48	12.11	20.77	30.72
	R100	3.10	6.75	10.89
	R200	1.08	3.57	0.45
	P200	3.20	10.43	24.74
M65 (30/65/5 S/P/F)	R14	69.33	42.54	26.31
	R28	14.24	23.59	29.61
	R48	10.40	20.20	25.30
	R100	2.13	5.76	8.31
	R200	1.11	3.28	4.14
	P200	4.56	4.63	6.33
M90 (10/90/0 S/P/F)	R14	70.48	28.07	16.74
	R28	14.87	29.23	30.44
	R48	10.93	24.33	27.52
	R100	0.31	7.45	9.44
	R200	2.09	4.20	4.15
	P200	1.32	6.72	11.72

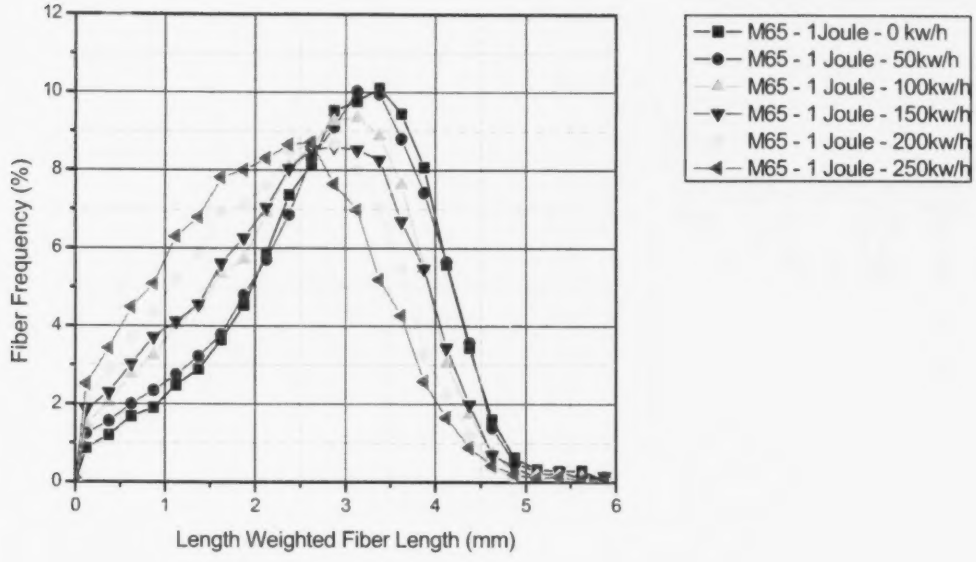
Fiber Frequency (%)
Length Weighted Fiber Length (mm)
M65 - 1Joule - 0 kw/h
M65 - 1 Joule - 50kw/h
M65 - 1 Joule - 100kw/h
M65 - 1 Joule - 150kw/h
M65 - 1 Joule - 200kw/h
M65 - 1 Joule - 250kw/h

Figure G-51. Change in fibre length distribution with Escher-Wyss refining: S/P/F 30/65/5 mixture, refined at SEL = 1 J/m

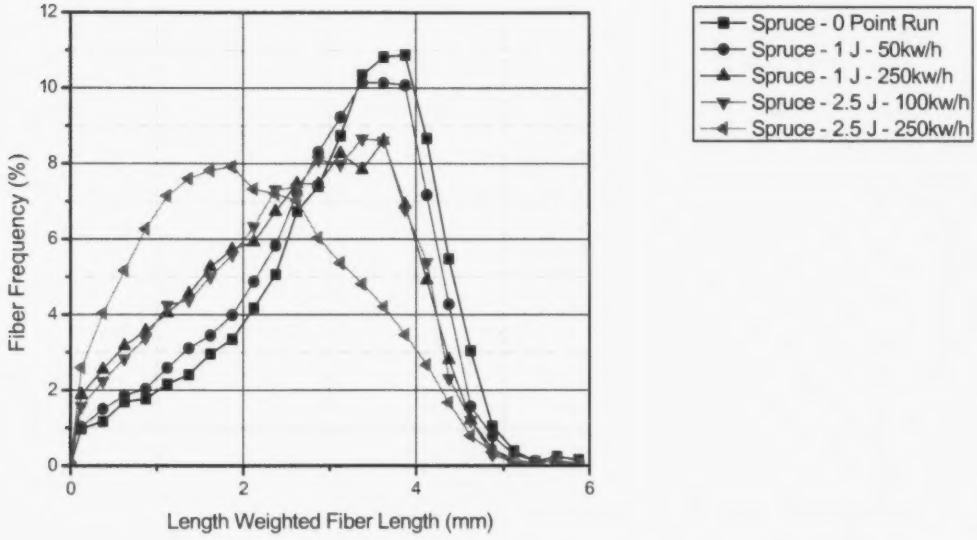
Fiber Frequency (%)
Length Weighted Fiber Length (mm)
Spruce - 0 Point Run
Spruce - 1 J - 50kw/h
Spruce - 1 J - 250kw/h
Spruce - 2.5 J - 100kw/h
Spruce - 2.5 J - 250kw/h

Figure G-52. Change in fibre length distribution with Escher-Wyss refining: Spruce

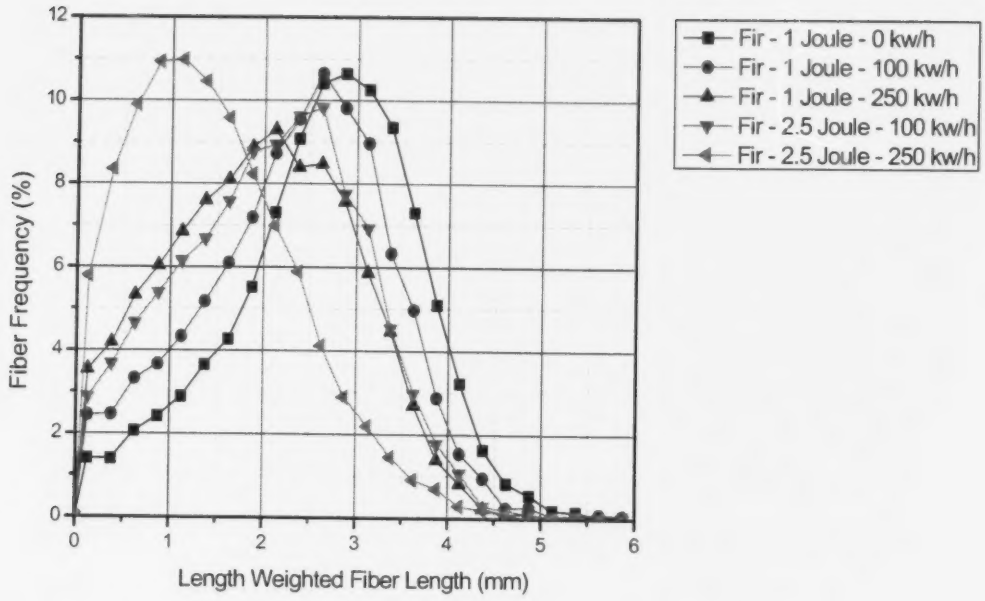

Figure G-53. Change in fibre length distribution with Escher-Wyss refining: Fir.

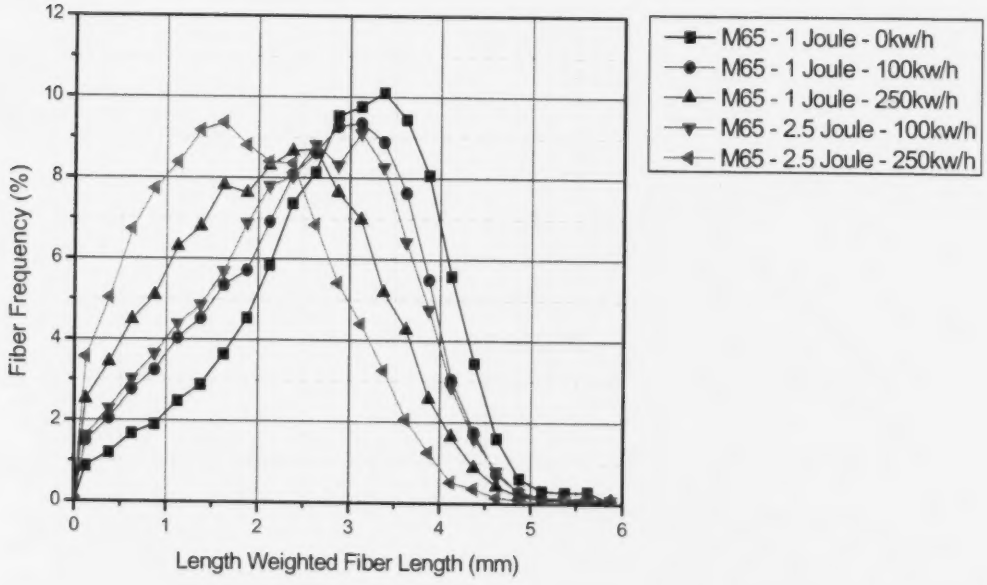

Figure G-54. Change in fibre length distribution with Escher-Wyss refining: S/P/F 30/65/5 mixture

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